THE EFFECT OF HEAVY METALS ON THE PERFORMANCE OF ROTATING BIOLOGICAL CONTACTORS (RBC)

By

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Dedicated to my wife, Zahra

THE EFFECT OF HEAVY METALS ON THE PERFORMANCE OF

ROTATING BIOLOGICAL CONTACTORS (RBC)

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CHAPTER I

INTRODUCTION

With the growth of technology, new products are developed and this, in turn, produces liquid waste which pollutes the biosphere. The liquid waste contains solutions of metallic ions which are toxic and hazardous to living organisms, human beings, aquatic life, etc. Hexavalent chromium concentrations of 5 mg/l and copper concentrations as low as 0.1 to 0.5 ppm are harmful to bacteria and other microorganisms (1). Therefore, the U. S. Public Health Service recommended limits of these chemical elements in water supplies.

The major sources of heavy metals are wastes from tanning industries, metal finishing shops, chemical products, etc. It is clear that the highest concentrations of heavy metals are contained in industrial wastes. Domestic wastes usually have low concentrations of metals.

Because of the toxicity of certain heavy metals in excessive concentrations to microorganisms and reduction of efficiency of treatment devices and the increasing reuse of water due to higher water demands for better quality, the pretreatment of discharges containing poisonous metals have become more desirable. Various purification processes utilized to purify the toxic discharges are activated sludges, trickling filters, rotating biological contactors, sedimentation procsses, and chemical precipitation.

The rotating biological contactor (RBC) has been used for several years (2). There are over 600 commercial installations for treatment of domestic and industrial wastes in West Germany, France, and Switzerland. At the present time, several commercial installations utilize this treatment in the United States.

The purpose of this study was to determine the effect of heavy metals on the performance of the rotating biological contactor system of biological wastewater treatment.

CHAPTER II

LITERATURE REVIEW

Heavy metals are known to have an effect on biological treatment processes such as activated sludge and trickling filters. The heavy metals listed below have been classified as having high to very high pollution potentials (3):

1) very high pollution: Ag, Au, Cd, Cr, Cu, Hg, Pb, Sb, Sn, Te, Zn.

2) high pollution potential: Ba, Bi, Fe, Mn, Mo, Ti, U.

The pollution of these metals is based on toxicity to individual species; however, the degree of toxicity is not clearly defined in many cases.

This study is concerned with Cr^{+6} (potassium dichromate and potassium chromate) and Cu^{++} in the form of copper sulfate. Studies have shown that these metals affect the operation of activated sludge, trickling filters, and other biological processes.

Chromium

A literature review of hexavalent (Cr^{+6}) studies shows the following effects on COD and BOD removal, microorganism respiration, and nitrifying bacteria.

Ingols (4) reported that the toxicity effect of chromium depends upon: a) the amount of organic matter present, e.g., strength of the sewage and type of organisms (autotrophic, heterotrophic); b) state of oxidation of the chromium (the valance of chromium); c) the presence or absence of oxygen. Ingols (5) concluded that the hexavalent chromium is much more toxic under anaerobic conditions than under aerobic conditions; however, trivalent chromium is relatively more toxic under aerobic conditions than under anaerobic conditions. Ingols (5) also showed that hexavalent chromium seems to be 100 times more toxic than is trivalent chromium.

Moore and McDermott et al. (6) in their observations on COD removal showed that hexavalent chromium (Cr^{+6}) had little effect on the removal of organic matter. They also found that the amount of chromium in the effluent was negligible when 0.5 mg/l and 2.0 mg/l hexavalent chromium (Cr^{+6}) concentrations were present in the influent. When Cr^{+6} was fed at 20 mg/l, it was occasionally found in small quantities in the effluent. With 5 mg/l and higher chromate feeds, variable but increasing amounts of Cr^{+6} passed through the system to emerge as either hexavalent or reduced chromium in the effluent. They also found that chromate noticeably restrained the development of odor in the primary clarifier and the development of *Sphaerotilus* in the mixed liquor.

Jenkins and Hewitt (7) studied the effect of chromium on nitrification. They found that when activated sludge which was able to oxidize 40-50 mg/l ammonia nitrogen to nitrate within 12 hours at 18-19^{o}C was subjected to 10 mg/l potassium chromate, the activated sludge failed to produce nitrate (NO_3^-) in 20 hours; however, nitrite (NO_2^-) formed instead. Within 48 hours following a second addition of sewage containing 10 mg/l of potassium chromate, formations of nitrite (NO_2^-) and nitrate (NO_3^-) were halted. Another experiment (8) showed that inhibition depends considerably upon the nature and concentration of the heavy metals, the frequency and duration of their discharge, and probably also on the operational condition in the plant. Influence on nitrifying bacteria is due, probably, to metal being either precipitated, adsorbed, or chelated by constituents of the sludge.

Ingols and Fetner (9) indicated that the presence of chromates will tend to cause a bulky sludge; that is, molds or Sphaerotilus will develop in preference to the zoogloeal masses in the presence of chromate. This development of a filamentous sludge was observed in attempts to obtain the comparison of toxicity with acclimated sludge over non-acclimated sludge. Results indicate that mold Mycelum have been seen at 500 mg/l concentration of sodium chromate, but no bacteria. Chromate at 500 mg/l concentration prevented the growth of bacteria to an extent that they did not compete for food and space in the agar plate. Molds, however, are sufficiently resistant to chromate at a concentration of 500 mg/l. In aerobic studies, Ingols and Hilly (10) found that sludge having a predominance of Sphaerotilus or zoogloeal masses responded differently to the same concentration of chromate. They conducted an experiment to measure respiration by determining the CO_2 produced and the number of viable organisms which could be placed on nutrient agar. E. coli (bacterium) and Saccharomyces ellipsoideus were chosen for the experiment, because they produce CO_2 under aerobic conditions. Results indicated that with a sodium chromate concentration of 10 mg/l there was no effect on the respiration of either E. coli or S. ellipsoideus.

Stone (11) found that potassium chromate at a concentration of 1 ppm reduced oxygen uptake by 18 percent. Studies by Dawson and Jenkins

(12) indicate that trivalent chromium is more toxic to activated sludge than is hexavalent chromium . Krieger and Moore (13) reported that both trivalent and hexavalent chromium are toxic at 1 or 2 ppm in the BOD test, but the trivalent form is generally more toxic.

Moore and McDermott et al. (6) showed that 10 mg/l of chromium would not interfere with conventional activated sludge treatment or anaerobic digestion of the sludges and that concentrations of chromium in the effluent were reduced by over 50 percent.

Jenkins and Hewitt (14) studied the effect of chromate on bacterial filters. They found that 0.1 part of Cr as K_2CrO_4 per 100,000 parts of sewage had little effect on the oxidation of organic matter or nitrification activity; one part of Cr per 100,000 parts of sewage slightly increased the amount of organic matter in the effluent and reduced the nitrification activity; 10 parts of Cr per 100,000 parts of sewage decreased nitrification 66 percent and 78 percent in two experiments and still further increased the amount of organic matter in the effluent. They also found that the upper part of the filter receiving 10 parts of Cr contained about twice as much deposited solid matter as did the control filter receiving no chromate. They also reported that in sewage containing 2.6 ppm chromium as K_2CrO_4 (0.7 ppm as Cr) decreased BOD values appreciably. Monk (15) found that a suspension of _A. aerogenes_ in contact with neutral chromium plating waste containing 5.2 ppm of Cr killed 16 percent of the organisms in two hours while 26 ppm Cr killed 46 percent. He also concluded that 50 ppm chromate as CrO_3 (26 ppm as Cr) might be permitted in sewage without affecting treatment efficiency. Jenkins and Hewitt (16) studied the effect of potassium chromate on the purification of sewage by activated sludge. Their findings indicated that 1 ppm of hexavalent chromium has no effect on the activity of nitrifying bacteria; 2 ppm concentration of Cl^{+6} caused some depression of nitrification, 10 ppm of Cl^{+6} destroyed the respiration activity of the sludge. A study concerned with the effects of metal finishing waste containing potassium chromate on percolating filters (14) showed that potassium chromate equivalent to 1 ppm hexavalent chromium had a perceptible effect on the BOD of the effluent and also reduced nitrification. The effect on the BOD of the effluent and nitrification was more severe at a 10 ppm concentration of chromium; 100 ppm Cr^{+6} reduced the oxidation of organic matter and ammonia markedly. According to Gellam (17) in his investigation dealing with metals, he noticed two important points. First, when the concentrations of metal and sewage were decreased in the same proportion, the toxic effect of metal remained approximately constant. Second, the toxicity of the metal depends greatly upon the pH of the solution. Thus, there was a marked drop in the toxicity of added trivalent chromium between 6 and 7. A trivalent chromium concentration up to 10 ppm was demonstrated (18) to have little effect on O_2 utilization, while 25 ppm concentrations caused an 80 percent reduction in a 24-hour period, and 14 percent reduction for a 5-day BOD. At 50 mg/l of trivalent chromium, inhibition of O_2 utilization was 27 percent for the 5-day period. Addition of 75 ppm chromium concentration inhibited O_2 utilization after the first day. The effect of increasing concentrations of hexavalent chromium on O_2 utilization of sewage up to a concentration of 100 ppm is not sufficient to exert a complete toxic effect, because observations have shown that O_2 utilization was 67 percent of the control sample after a 5-day period. At Grand Prairie, Texas, Wells (19) found that poor settling of activated sludge and low treatment efficiency were caused by the presence of chromium in the aeration liquor. Also high dissolved oxygen values were found in the activated sludge. Spencer (20) concluded from a study on a trickling filter that chromates ranging from 3.5 to 67.5 ppm stopped biological action. Jenkins and Hewitt (14) reported that in sewage containing 2.6 ppm chromium as K_2CrO_4 (0.7 ppm as Cr) decreased BOD values appreciably. The following conclusions have been made during Bozich's studies (21) upon lead, nickel, and hexavalent chromium by the activated sludge processes:

1) Nitrification begins to be retarded between 0 and 1 ppm concentrations of hexavalent chromium, and nitrification is retarded completely at 4 ppm of hexavalent chromium.

2) 16.5 percent removal of nickel is achieved at an influent concentration of 24 ppm.

3) The percentage of chromium removed by activated sludge is independent of concentration, with 1.5 to 3 percent of the metal fed being removed at concentrations from 1 through 24 ppm.

4) Nickel concentrations between 8 and 12 ppm and chromium concentrations between 2 and 4 ppm start to lower the efficiency of the activated sludge processes as indicated by the O_2 consumption value of the effluent.

Copper

A literature review of copper (Cu^{++}) studies shows the following effects:

Shumate (22) found that the respiratory activity of sewage organisms is significantly affected by low copper concentrations. He concluded that copper at 45 mg/l is not sufficient to halt biological activity in aerobic biological waste treatment processes. His experiments show that adding copper continuously to the influent sewage results in a linear decrease in respiratory activity. Heukelekian and Gelman (23) noted that several factors affecting the toxicity of metal ions toward sewage and activated sludge are pH, substrate concentration, and the amount of biomass. To this, Sawyer, Frame and Wold (24) added the factor of temperature. They showed that increasing temperature decreased the toxicity of the hydroxyl ion. Dawson (12) reported that Cu^{++} depressed respiration more than did Ni and CN^{-}. Barth and Ettinger (25) found that a continuous copper concentration of 0.4 mg/l did not increase the effluent COD appreciably, but copper at 1.2 mg/l increased the effluent COD significantly. The findings of these studies also showed that continuous doses of copper at 10 mg/l caused failure in combined sludge digestion. According to Sierp and Fransemeier (26), copper had a detectible effect in increasing turbidity and decreasing nitrification at 1 ppm, and had a slight effect on the BOD of the effluent from laboratory-scale activated sludge units.

Gellman (17) showed that at copper concentrations of 0.05 ppm, a 20 percent BOD reduction was noted using both manometric and dilution techniques. The concentration of copper which had a detectibe effect on the activated sludge process was reported as 1 ppm. He also found that the toxicity of copper decreased between pH 5 and 6.5. This could be expected because the solubility of copper decreases with increasing pH of the solution. Southgate (27) concluded that washes from the pickling of copper retarded or stopped biological action in trickling filters. Placak, Rucchoft, and Snapp (29) showed that copper has an extreme effect on BOD. The results indicated that concentrations as low as 0.01 ppm caused detectible reduction in BOD, and at 0.05 ppm copper, BOD was decreased by about 23 percent. Copper concentration at 1 ppm will permit only about a 34 percent BOD recovery. Copper concentrations above 0.05 ppm inhibit nitrification completely.

McDermott and Moore et al. (29) reported that the effluents of the activated sludge units receiving 10, 15, and 25 mg/l copper fed as copper sulfate were generally of lower quality than those of the control units. They observed that turbidity increased with increasing copper concentration, and a maximum copper concentration which had no significant effect on effluent turbidity was 0.8 mg/l. They also found that the maximum concentration of copper that did not have a detectible effect on BOD and COD of the effluent was 1 mg/l.

CHAPTER III

MATERIALS AND METHODS

Test Unit

The pilot plant laboratory-scale rotating biological contactor utilized in this research work was comprised of a tank made of plexiglass divided into six stages with four ethylene discs in each stage (Figure 1). Each disc was approximately six inches in diameter and 1/8 inch thick. Total disc surface area was 9.43 square feet for the entire unit. Three or four small plexiglass paddles were placed between two discs to make sufficient turbulence for complete mixing of the wastewater and to keep the mixed liquor solids in suspense.

The unit consisted of five baffles to separate each stage with an opening at the base of each baffle to permit flow through the unit. The last stage consisted of an outlet to direct the effluent out of the unit and into the sanitary sewer. The tank volume was 8.97 liters. Twenty-four discs mounted on a shaft rotated by a Barcool speed reducer motor. The rotational speed of the discs was set at approximately 9 rpm, and 40 percent of the surface of the discs was submerged into the liquor.

The purpose of the study was to observe and attempt to explain the effects of heavy metals such as copper sulfate and hexavalent chromium on the RBC system. Hexavalent chromium (Cr^{+6}) was introduced to the synthetic waste in two different forms, $K_2Cr_2O_7$ and K_2CrO_4.

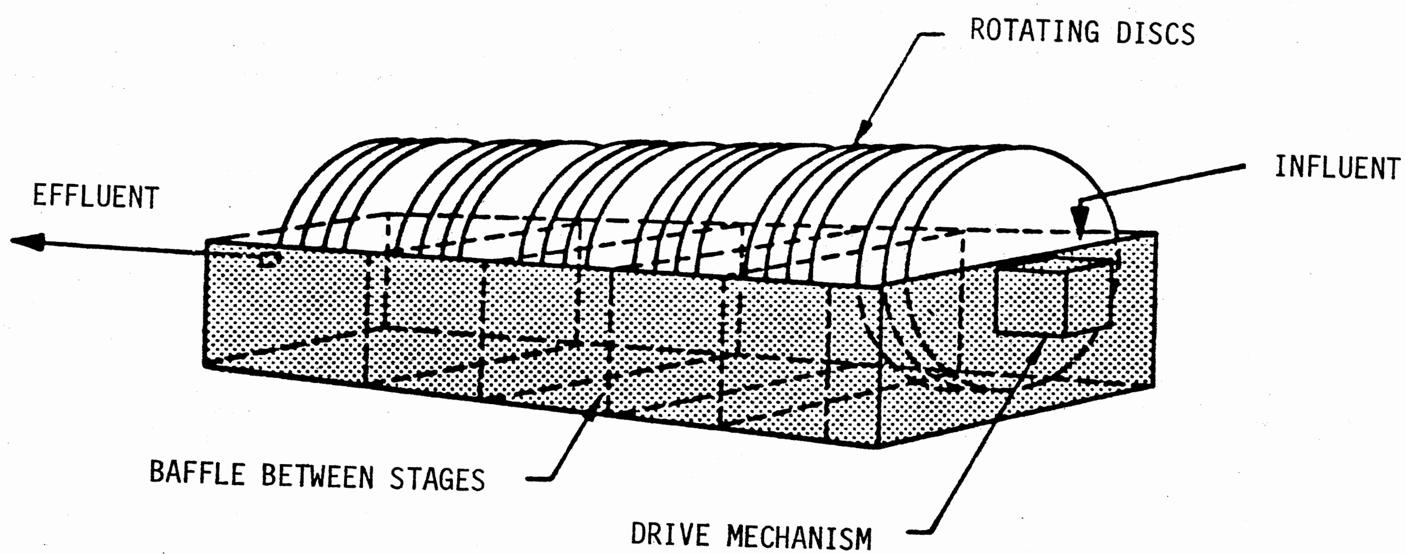

Figure 1. Schematic Diagram of Laboratory Scale Rotating Biological Contactor (RBC)

Copper was fed to the influent sewage as $CuSO_4$.

Hydraulic loading was 2.8 gpd/ft^2 for Cr^{+6}, which was fed in various forms and concentrations such as K_2CrO_4 in 1.0, 2.0, 3.0, and 4.0 mg/l and $K_2Cr_2O_7$ in 1.0, 2.0, 3.0, and 20.0 mg/l.

Copper ($CuSO_4$) was fed at various concentrations such as 0.5, 1, 4, and 10 mg/l for two different hydraulic loadings--these two hydraulic loadings being 0.7 and 3 gpd/ft^2.

The flow was controlled by a constant head tank which received a continuous flow of tap water (Figure 2). The flow from the constant head tank was adjusted by a valve combined with a flowmeter on the tank outlet. Water from the constant head tank was fed by gravity into a wet well, where it was mixed with the concentrated synthetic waste to approach the desired influent concentration. The synthetic waste was pumped to the wet well using a Cole-Parmer pump. After mixing, the desired synthetic waste was fed by gravity into the first stage of the test unit.

Synthetic Waste

The synthetic waste used in this experiment was composed of glucose ($C_6H_{12}O_6$) as the carbon source in combination with nutrients and buffer solution in order to provide microbial growth. In this experiment, carbon was considered as the limiting factor, and other nutrients and buffer solution were fed in sufficient amount (Tables I and II). The waste was prepared in a concentrated solution and introduced into the wet well and mixed with a specific amount of tap water flow in order to achieve the desired organic matter concentration. The organic concentration was maintained at 400-500 mg/l for all hydraulic loading

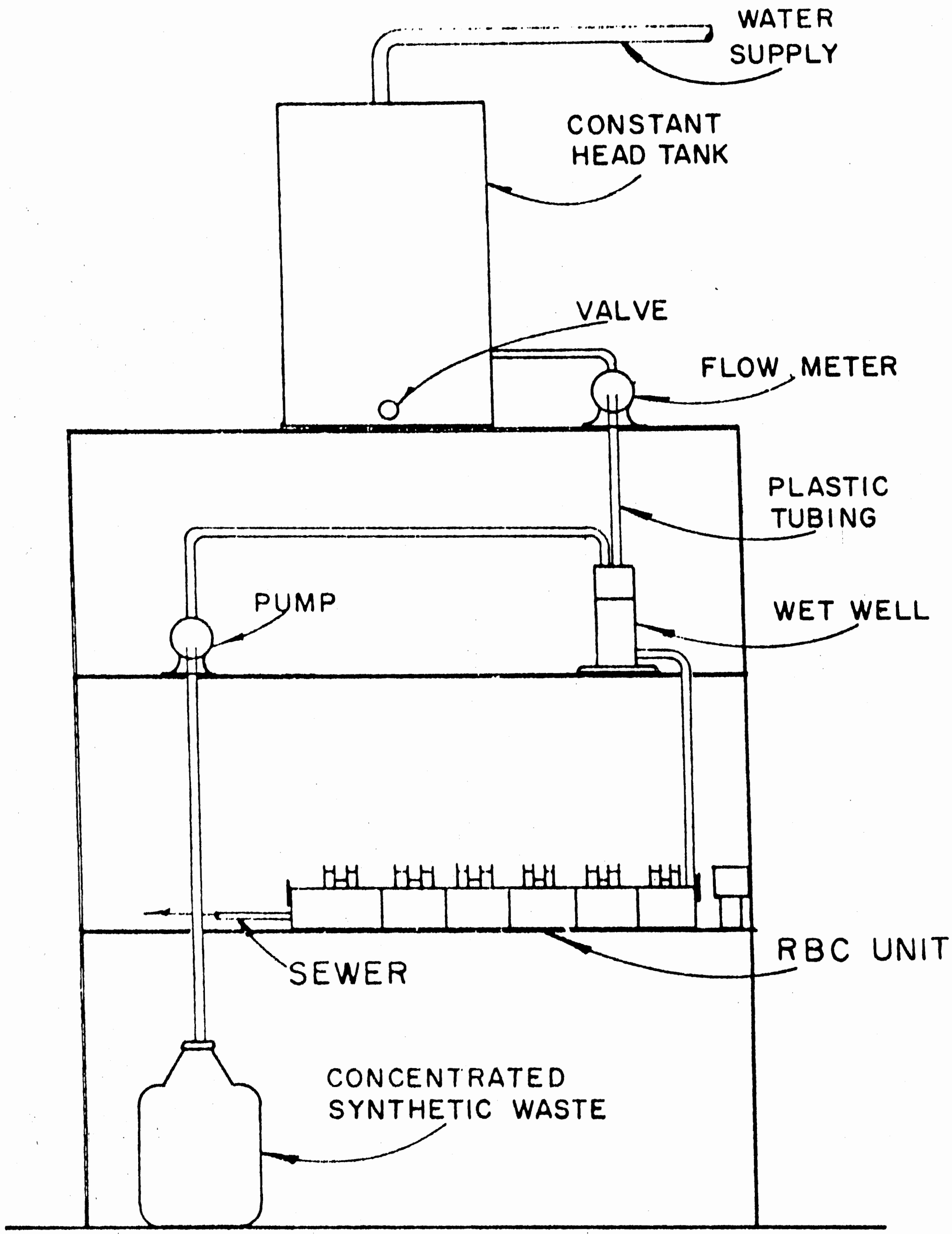

Figure 2. Experimental Apparatus

TABLE I

HYDRAULIC LOADING AT 2.8 gpd/ft^2 FOR Cr^{+6}, 3.0 gpd/ft^2 FOR Cu^{+2} AND RELATIVE COMPOSITION OF SYNTHETIC WASTE FOR 10,000 mg/l GLUCOSE CONCENTRATION

Constituent	Concentration (mg/l)
Glucose	10,000
$(NH_4)_2SO_4$	5,000
$HgSO_4 \cdot 7H_2O$	1,000
$FeCl_3 \cdot 6H_2O$	
$CaCl_2$	100
$MnSO_4 \cdot H_2$	75
KH_2PO_4	3,487
K_2HPO_4	11,259
Tap water	to volume

Synthetic waste was introduced to the wet well at 3.6 ml/min and mixed with 71 ml/min tapwater, yielding a 483 mg/l glucose concentration, which was fed to RBC.

TABLE II

HYDRAULIC LOADING OF 0.7 gpd/ft^2 FOR Cu^{++} AND RELATIVE COMPOSITION OF SYNTHETIC WASTE FOR 2,360 mg/l GLUCOSE CONCENTRATION

Constituent	Concentration (mg/l)
Glucose	2,360
$(NH_4)_2$	1,180
$MgSO_4 \cdot 7H_2O$	250
$FeCl_3 \cdot 6H_2O$	1.25
$CaCl_2$	25
$MnSO_4 \cdot H_2O$	19
KH_2PO_4	872
K_2HPO_4	2,815
Tap water	to volume

Synthetic waste was introduced to the wet well at 3.6 ml/min and mixed with 14.2 ml/min tap water, yielding 477 mg/l glucose concentration, which was fed to RBC.

(0.7, 2.8, and 3.0).

Operation and Sampling Procedures

The test unit was seeded with 300 m. of primary effluent from the Stillwater municipal sewage treatment plant, and was run as a batch process for several days before beginning continuous flow operation.

The experiment consisted of two parts. In the first part, the test unit was fed with hexavalent chromium at various concentrations. Before any chromium was added, the RBC was run as a continuous flow unit for a period of about three weeks. This was done to ensure that good growth would accumulate on the discs. When the results of periodic COD analyses became relatively constant, the system was assumed to have approached equilibrium. After achieving equilibrium, the values of three comparable runs were averaged to show the performance of the unit. This value was selected as the control condition which would be compared with subsequent analyses obtained during the addition of various chromium concentrations. Before the second part of the investigation was begun, the unit was cleaned. Then the RBC was run as a batch operation for several days using the same amount of primary effluent as used in the first experiment. The system was then converted to a continuous flow unit for a period of one week to ensure a good film accumulation on the discs. When the unit reached equilibrium, the values of two or three comparable CODs were averaged to represent the control condition.

The second part of the investigation studied the effect of the addition of copper sulfate at various concentrations and at different hydraulic loadings on the performance of RBC.

Samples were taken at eight locations in the system for each run. These locations were the influent beginning of the first stage, end of the first stage, and end of each of the remaining stages. The sample from the end of the sixth stage represented the process effluent.

The analytical tests performed during this study were COD, hexavalent chromium, and copper.

COD

Chemical oxygen demand (COD) was used to analyze the organic matter present in the waste. The dichromate reflux method was used; the procedure is described in Standard Methods for the Examination of Water and Wastewater, 14th edition (30).

Metal Determination

Hexavalent chromium determination was made according to the procedure described in the Handbook of Water Analysis by Hach Chemical Company (31).

Copper sulfate utilized during the analysis was determined by the colorimetric method, which is explained in the Handbook of Water Analysis by Hach Chemical Company, also (31).

CHAPTER IV

RESULTS AND DISCUSSION

This investigation consisted of two parts: the first part was the effect of hexavalent chromium on performance of the RBC. Two forms of chromium (potassium dichromate $K_2Cr_2O_7$) and potassium chromate (K_2CrO_4) were studied at four different concentrations, and a constant hydraulic loading of 2.8 gpd/ft^2. The second was the effect of copper sulfate on the performance of the RBC. Copper sulfate ($CuSO_4$) was introduced into the influent at 0.5, 1, 4, and 10 mg/l at hydraulic loadings of 0.7 and 3 gpd/ft^2.

$K_2Cr_2O_7$ Studies

The performance of the RBC was based on COD removal as a function of the stages and is shown in Figures 3 through 21. Generally, the COD removal followed first order kinetics as expected. Figure 3 describes the COD removal when no $K_2Cr_2O_7$ or K_2CrO_4 was added (control condition). It shows that most removal occurred during the first three stages, and COD removal efficiency was about 78 percent. Figures 4 to 7 represent the addition of $K_2Cr_2O_7$ at concentrations of 1, 2, 3, and 20 mg/l, respectively. Figure 4 shows the performance of the unit at 1 mg/l $K_2Cr_2O_7$. It shows that the initial COD of 460 mg/l was decreased to 55 mg/l by the time it left the unit. This gave a removal of 88 percent. Most of the removal was accomplished by the first three

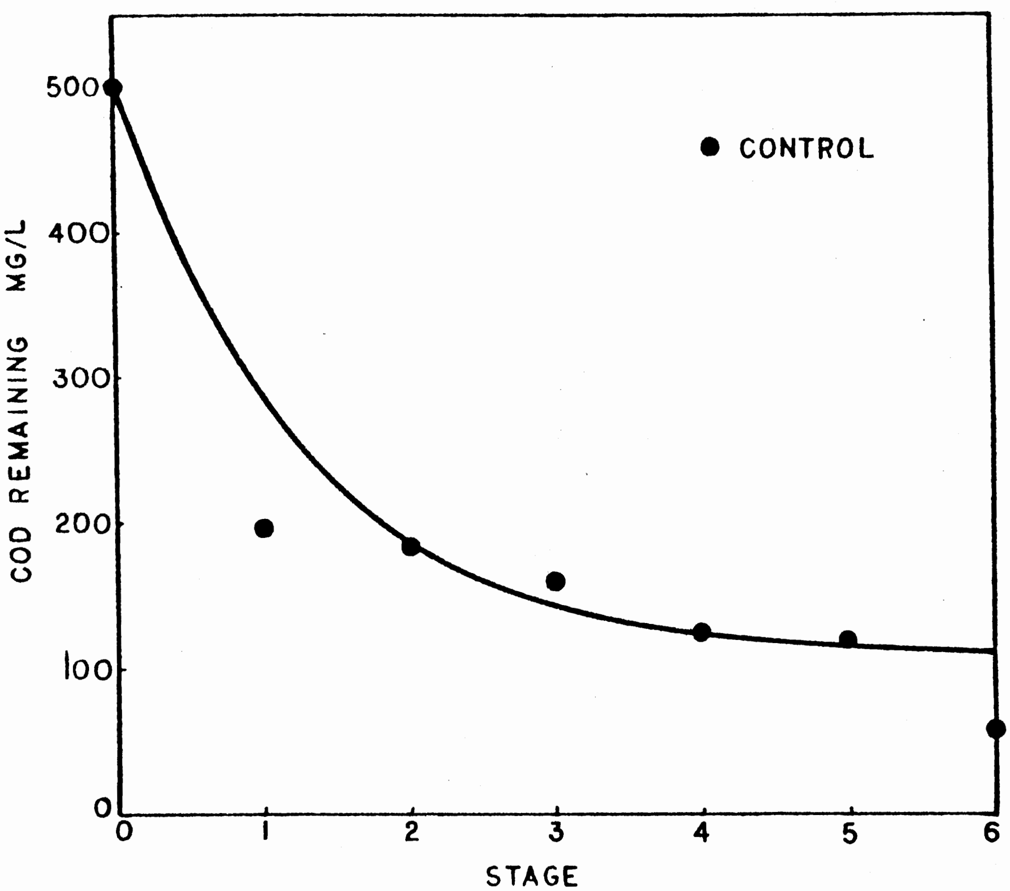

Figure 3. COD Remaining vs. Stage for Hydraulic Loading of 2.8 gpd/ft^2 When no $K_2Cr_2O_7$ or K_2CrO_4 was Added

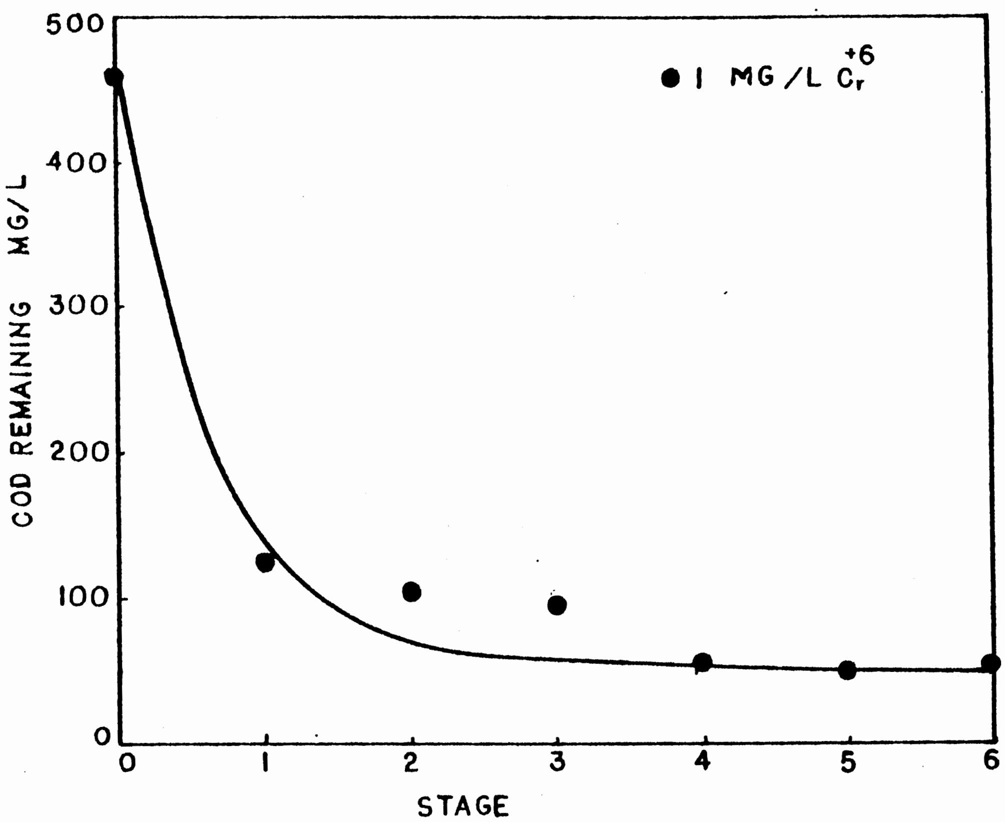

Figure 4. COD Remaining vs. Stage for Hydraulic Loading of 2.8 gpd/ft^2 With 1 mg/l Concentration of $K_2Cr_2O_7$

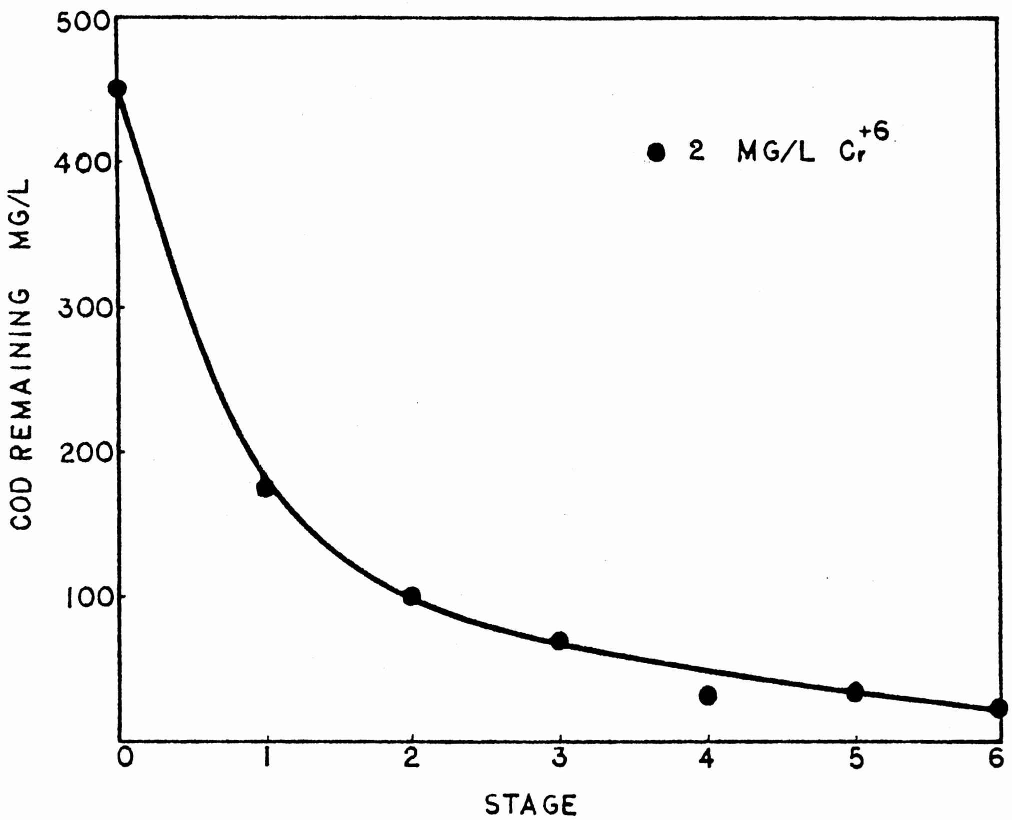

Figure 5. COD Remaining vs. Stage for Hydraulic Loading of 2.8 gpd/ft^2 When 2 mg/l $K_2Cr_2O_7$ was fed

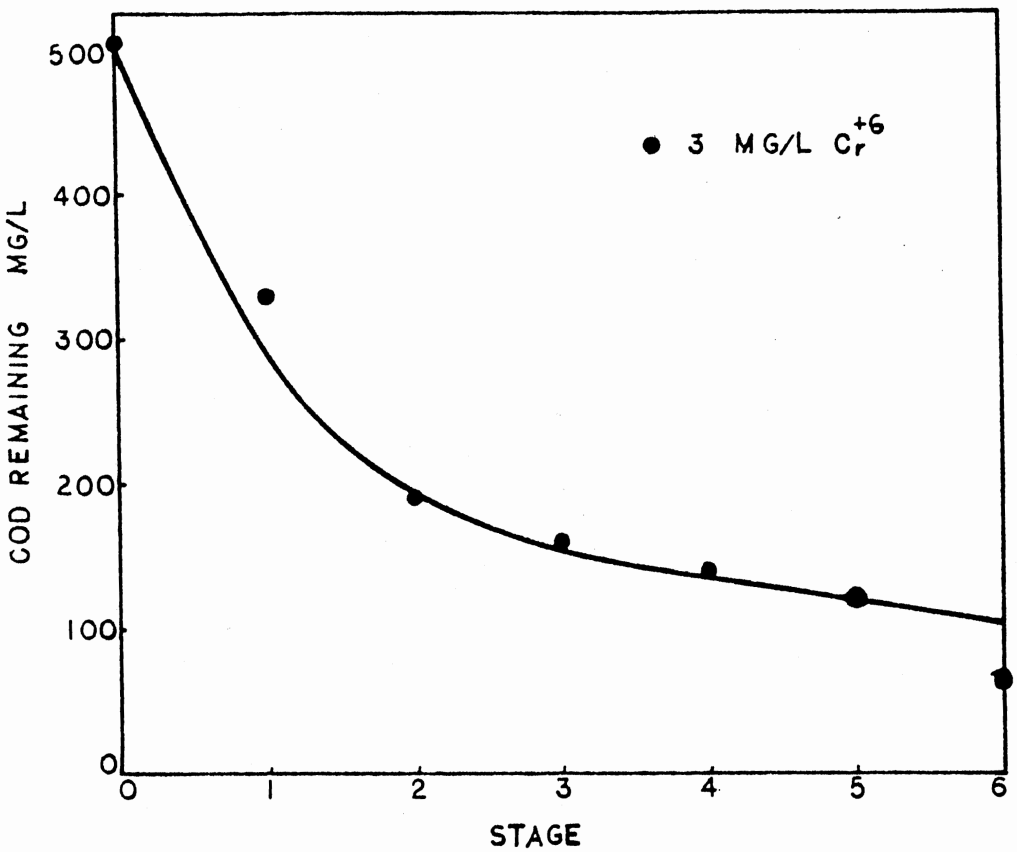

Figure 6. COD Remaining vs. Stage for Hydraulic Loading of 2.8 gpd/ft^2 When 3 mg/l $K_2Cr_2O_7$ was fed

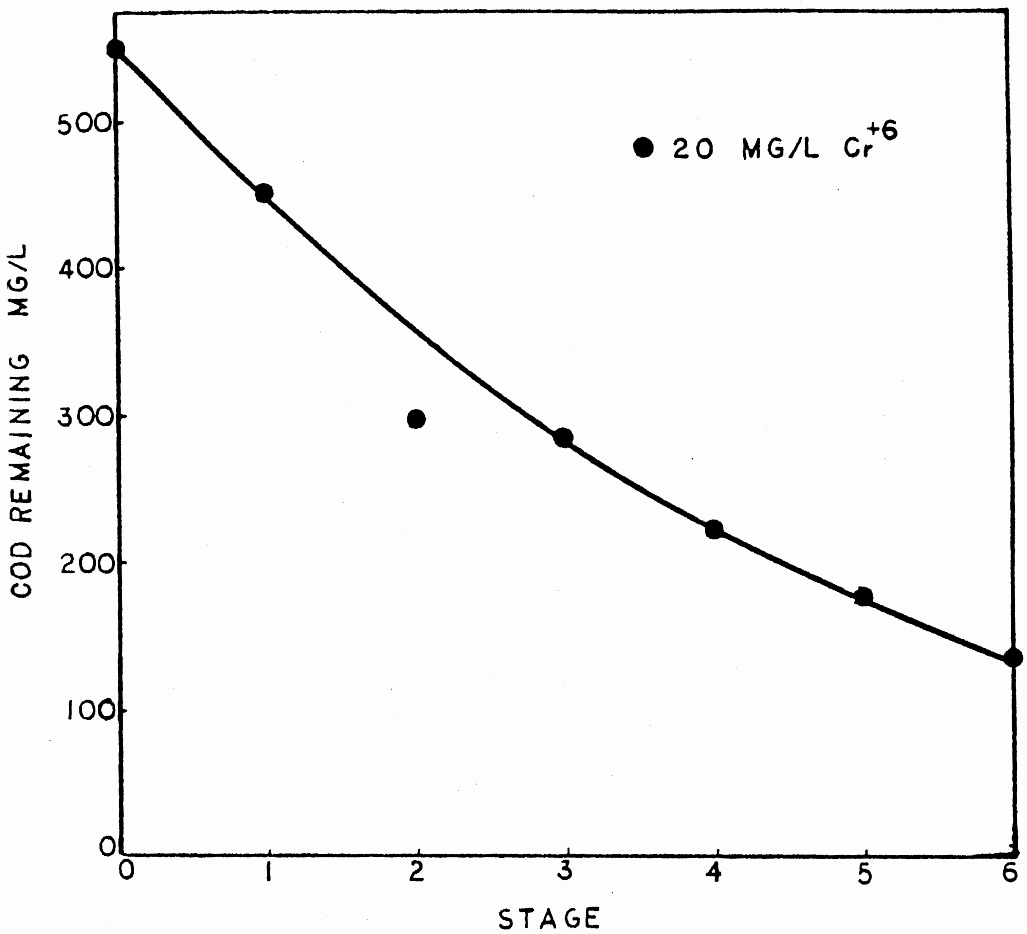

Figure 7. COD Remaining vs. Stage for Hydraulic Loading of 2.8 gpd/ft^2 With 20 mg/l $K_2Cr_2O_7$

stages (79 percent removal). The addition of 2 mg/l $K_2Cr_2O_7$ shown in Figure 5 indicates that most of the removal occurred during the first three stages, with a total removal efficiency of 94 percent. Figure 6 shows the COD removal achieved when 3 mg/l of $K_2Cr_2O_7$ was present in the wastewater at an overall removal efficiency of 80 percent. This efficiency was less than that achieved by the unit receiving either 1 mg/l of $K_2Cr_2O_7$ or 2 mg/l of $K_2Cr_2O_7$. Figure 7 shows that the rate of removal of COD was greatly reduced by 20 mg/l $K_2Cr_2O_7$; however, approximately 75 percent of the COD was removed by the RBC.

K_2CrO_4 Studies

Figures 8 to 11 represent four different concentrations of chromium in the form of K_2CrO_4 (1 to 4 mg/l). When chromium was fed at 1 mg/l, the RBC was able to reduce the COD from about 400 mg/l to 25 mg/l, with an overall removal efficiency of 87 percent (Figure 8). The performance of the RBC at 2 mg/l concentration of K_2CrO_4 is shown in Figure 9. It shows that the majority of removal occurred by the end of the fourth stage, and the overall removal efficiency was about 93 percent. K_2CrO_4 at 3 mg/l and 4 mg/l have been depicted in Figures 10 and 11, respectively. Figure 10 shows that almost 92 percent of the COD was removed by the RBC. Figure 11 shows that approximately 95 percent of the COD was removed by the RBC.

Copper Studies

The performance of the control unit at a hydraulic loading of 0.7 gpd/ft^2 is shown in Figure 12. It is seen that a COD removal efficiency of 87 percent was achieved. It appears that 0.5, 1, 4, and 10

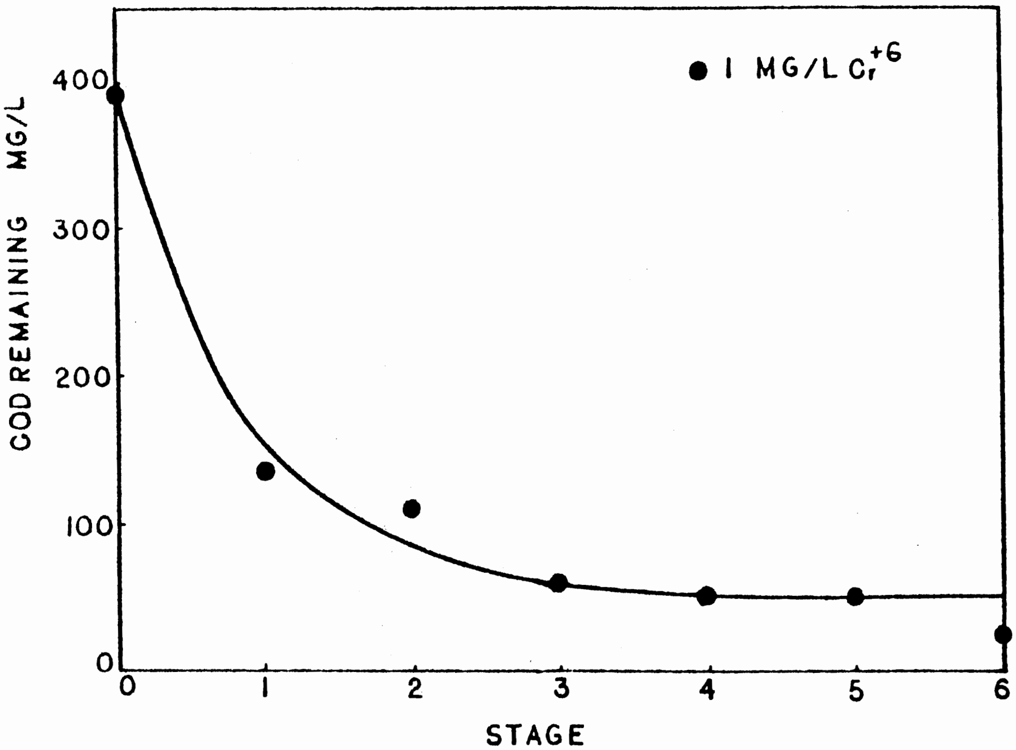

Figure 8. COD Remaining vs. Stage for Hydraulic Loading of 2.8 gpd/ft^2 When 1 mg/l K_2CrO_4 was fed

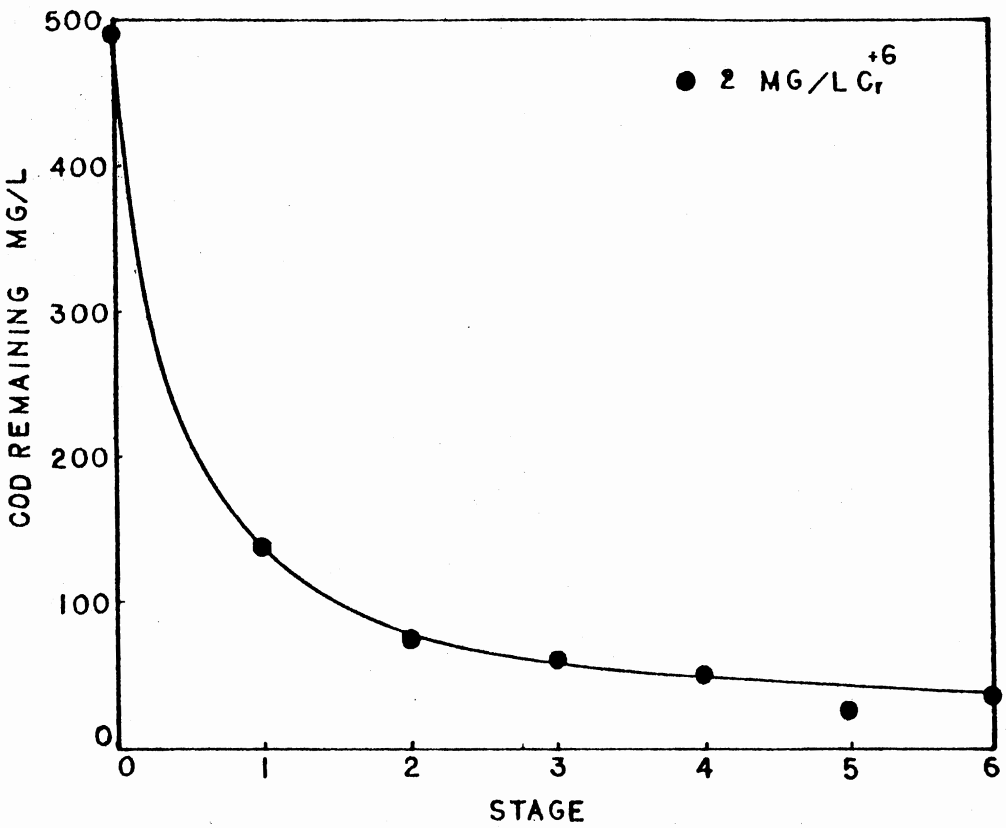

Figure 9. COD Remaining vs. Stage for Hydraulic Loading of 2.8 gpd/ft^2 K_2CrO_4 was fed

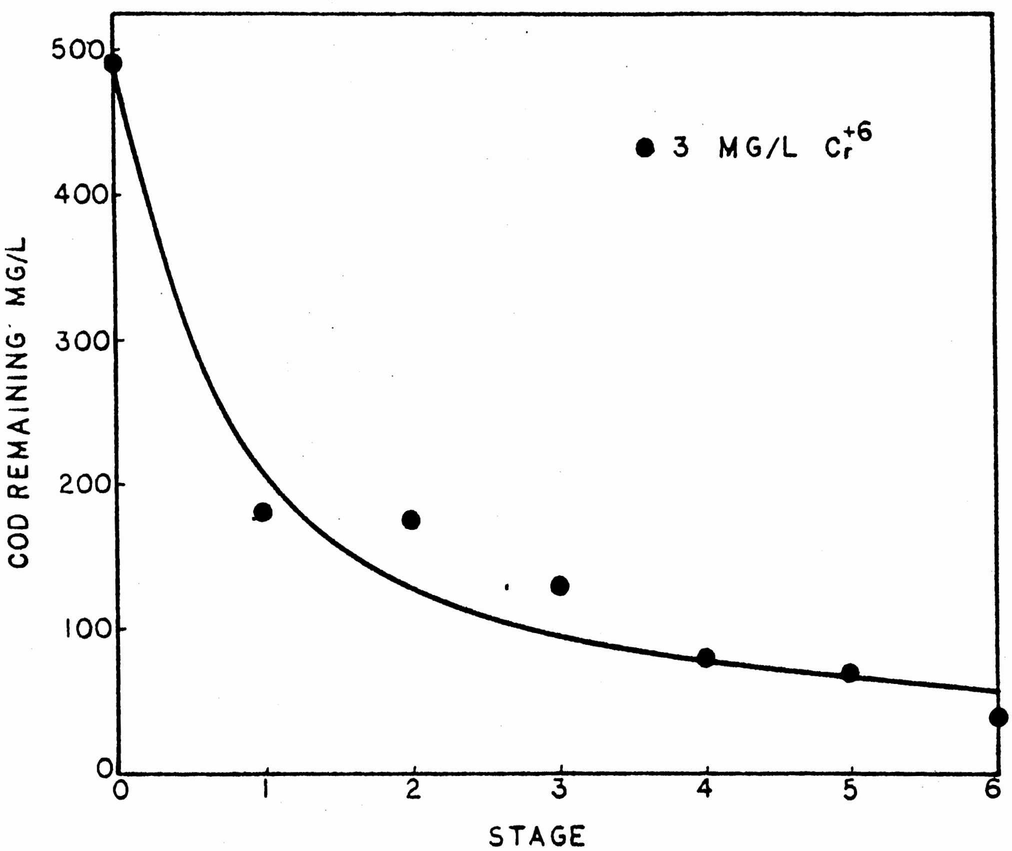

Figure 10. COD Remaining vs. Stage for Hydraulic Loading of 2.8 gpd/ft^2 When 3 mg/l K_2CrO_4 was fed

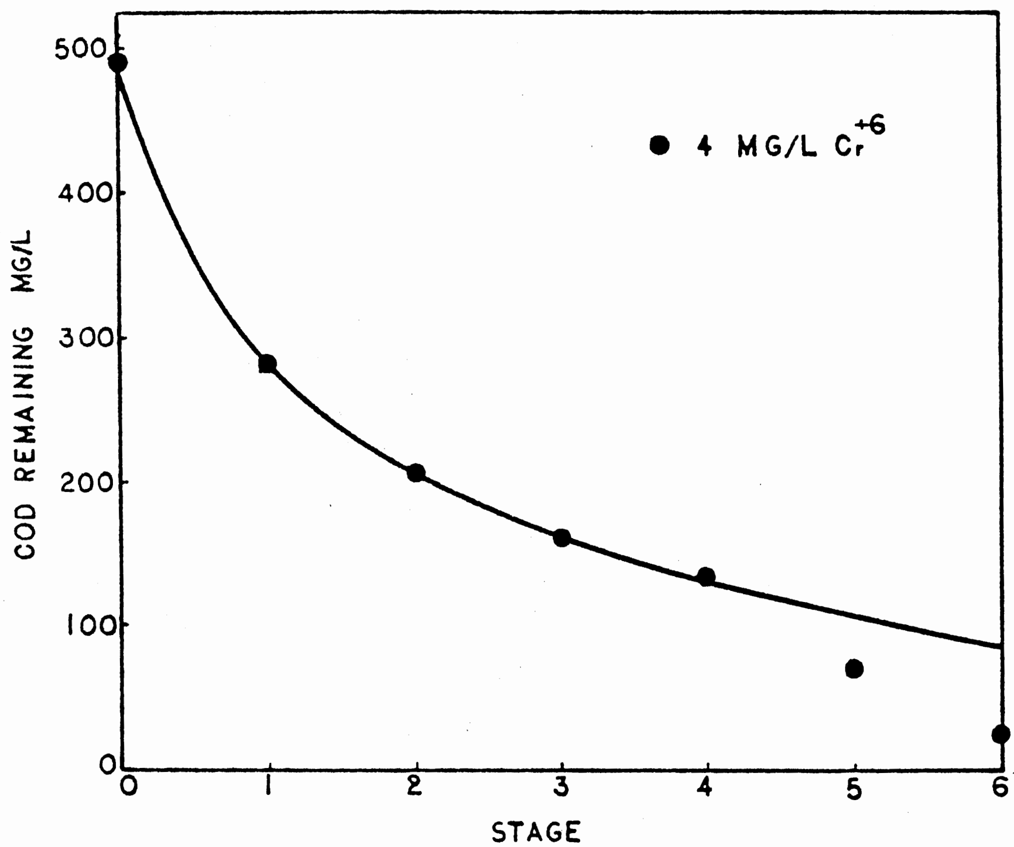

Figure 11. COD Remaining vs. Stage for Hydraulic Loading of 2.8 gpd/ft^2 When 4 mg/l K_2CrO_4 was fed

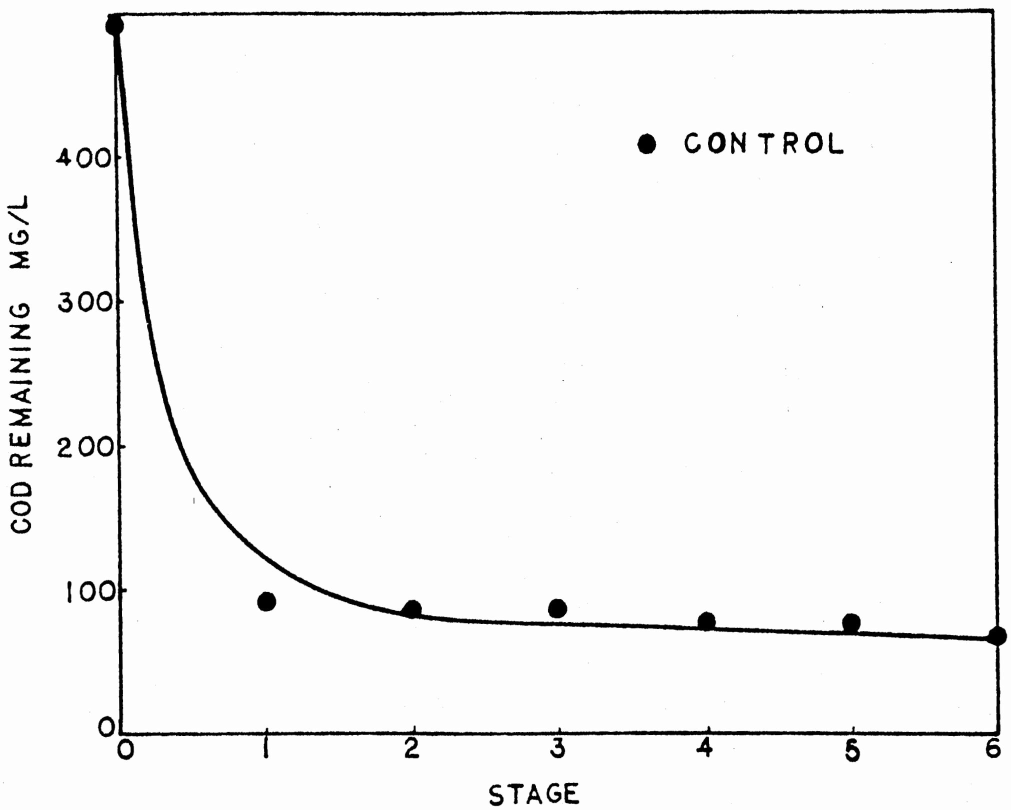

Figure 12. COD Remaining vs. Stage for Hydraulic Loading of 0.7 gpd/ft^2 (Control)

mg/l copper had no effect on the RBC. When the wastewater contained 0.5 mg/l Cu, the overall removal efficiency was 95 percent (Figure 13). At a Cu concentration of 1 mg/l, the overall efficiency was 93 percent (Figure 14). Copper concentrations of 4 mg/l and 10 mg/l gave COD removal efficiencies of 92 percent and 93 percent, respectively (Figures 15 and 16).

The response of the control unit to a hydraulic loading of 3 gpd/ ft^2 is shown in Figure 17. It was found that a COD removal efficiency of 78 percent was approached. It appears that 0.5, 1, 4, and 10 mg/l copper had no effect on the RBC. When the wastewater concentration of copper was 0.5 mg/l, the overall removal efficiency was 90.6 percent (Figure 18). At a Cu concentration of 1 mg/l, the overall removal efficiency was 70 percent (Figure 19). Figures 20 and 21 show the performance of the unit when copper at 4 and 10 mg/l was added, the COD removal efficiency was 88.5 percent and 91.4 percent, respectively.

Summary of Results

Addition of 1, 2, and 3 mg/l concentrations of $K_2Cr_2O_7$ did not have an adverse effect on the COD removal. An addition of 20 mg/l of $K_2Cr_2O_7$ had a slight effect on the COD removal. This can be seen in Table III. An increase in treatment efficiency did occur when chromium (Cr^{+6}) was fed as $K_2Cr_2O_7$ at concentrations of 1, 2, and 3 mg/l. This was unexpected. At 3 mg/l chromium, a slight decrease in COD removal efficiency was observed when compared to 1 mg/l and 2 mg/l chromium wastewaters. Table IV shows that $K_2Cr_2O_7$ removal efficiencies of 65-80 percent were achieved by the RBC. This left low levels of $K_2Cr_2O_7$ in the effluent except at the 20 mg/l loading. At this

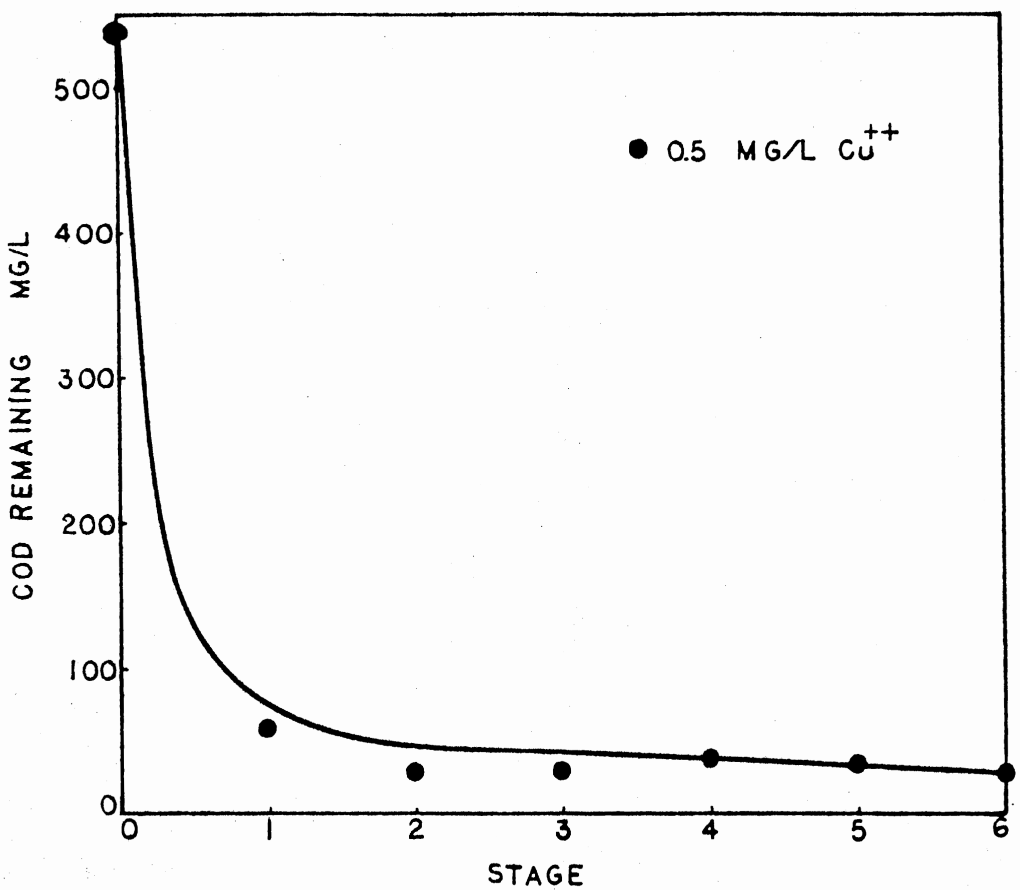

Figure 13. COD Remaining vs. Stage for Hydraulic Loading of 0.7 gpd/ft^2 When 0.5 mg/l Copper was fed

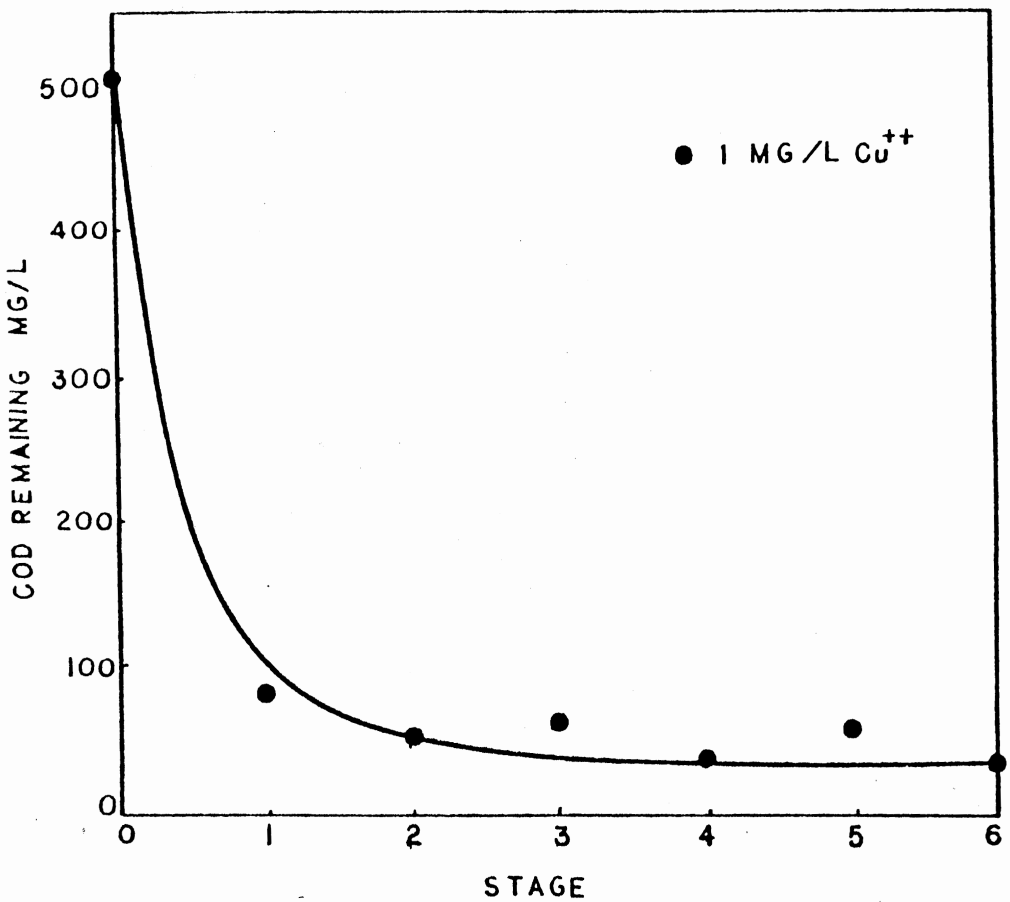

Figure 14. COD Remaining vs. Stage for Hydraulic Loading of 0.7 gpd/ft^2 When 1 mg/l Copper was Added

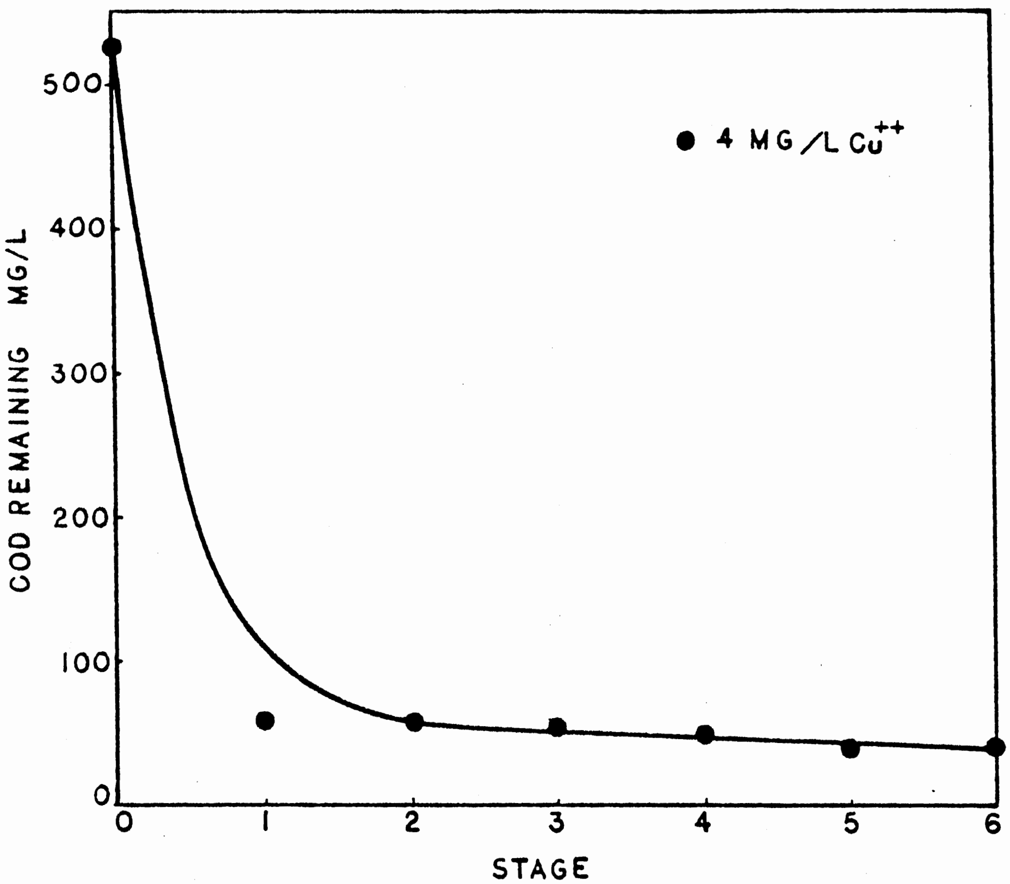

Figure 15. COD Remaining vs. Stage for Hydraulic Loading of 0.7 gpd/ft^2 When 4 mg/l Copper was fed

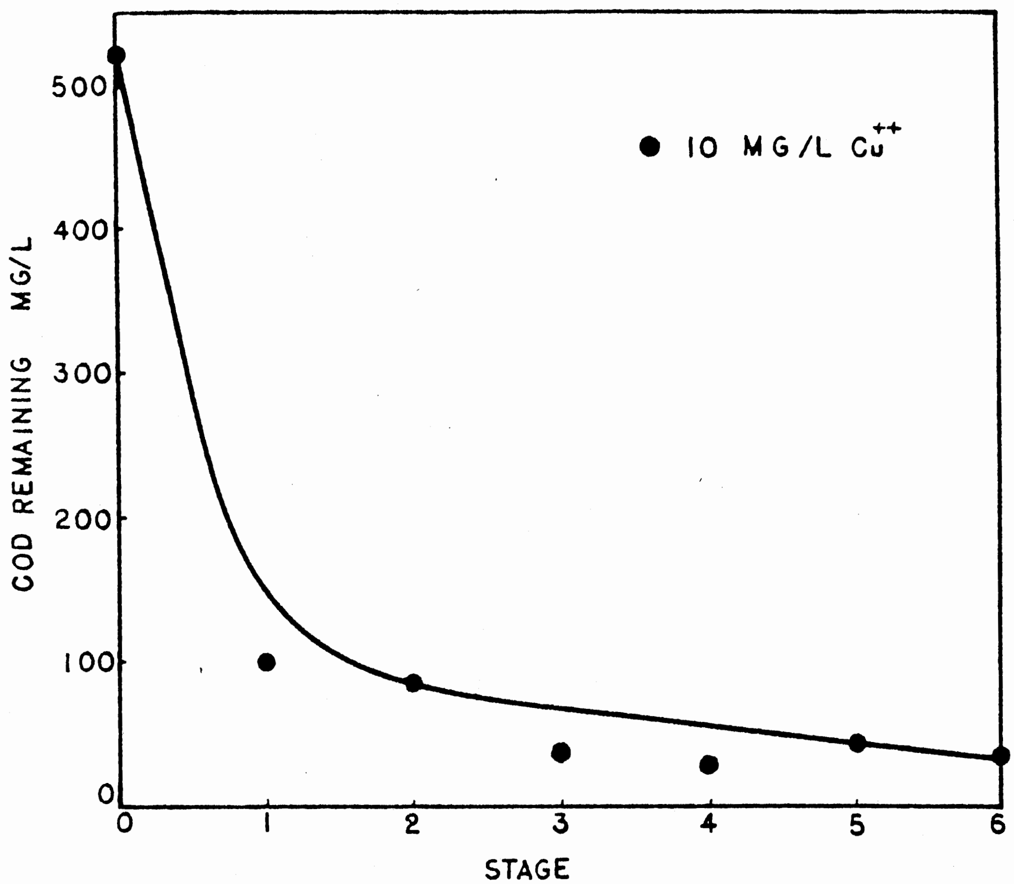

Figure 16. COD Remaining vs. Stage for Hydraulic Loading of 0.7 gpd/ft^2 When 10 mg/l Copper was fed

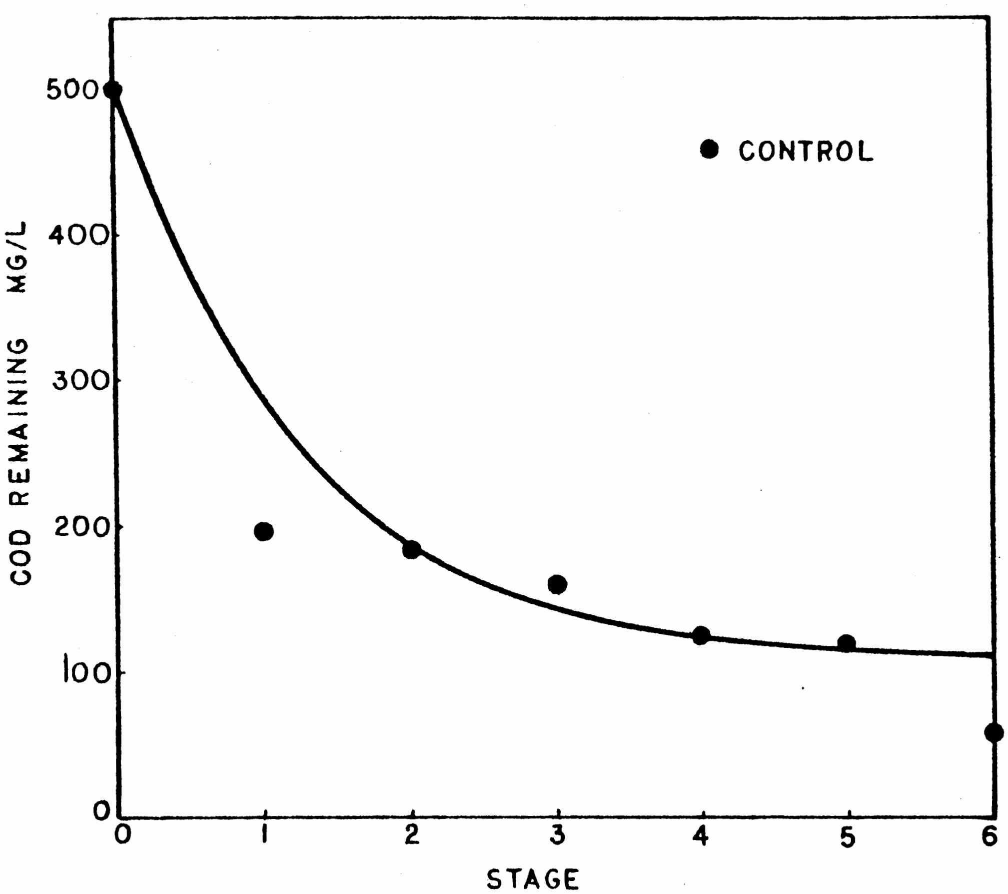

Figure 17. COD Remaining vs. Stage for Hydraulic Loading of 3 gpd/ft^2 When no Copper was Added

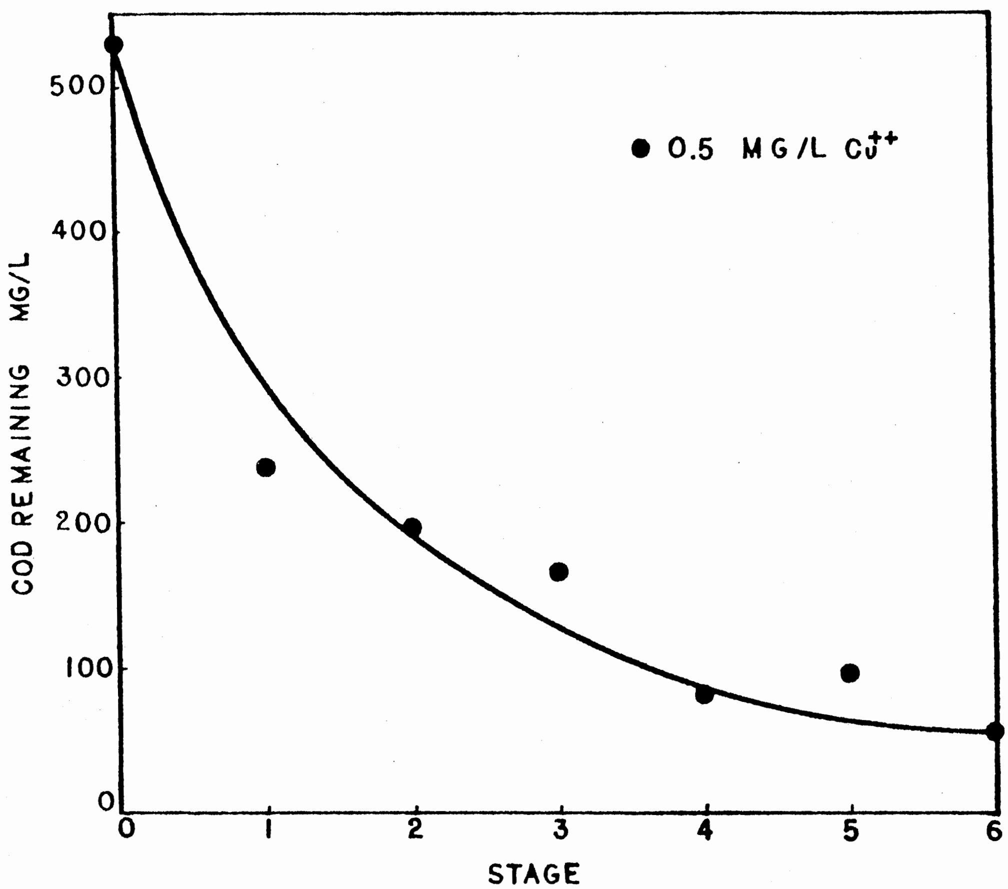

Figure 18. COD Remaining vs. Stage for Hydraulic Loading of 3 gpd/ft^2 When 0.5 mg/l Copper was fed

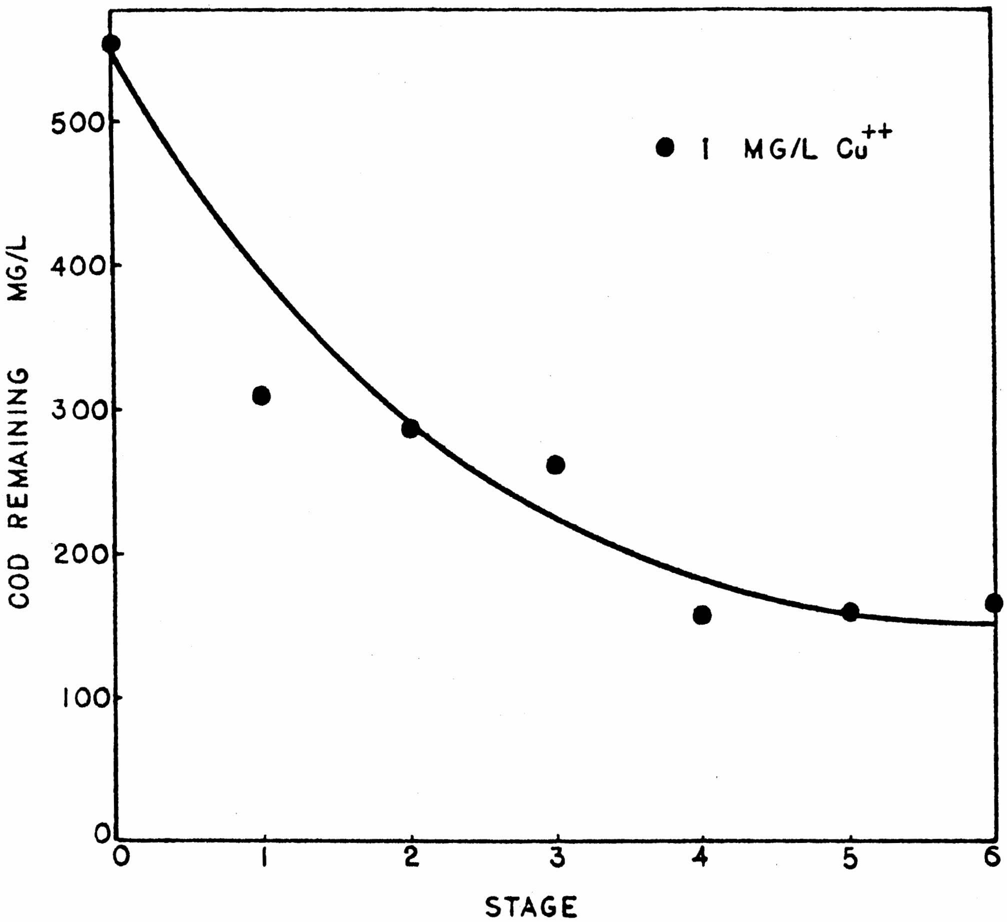

Figure 19. COD Remaining vs. Stage for Hydraulic Loading of 3 gpd/ft^2 When 1 mg/l Copper was Added

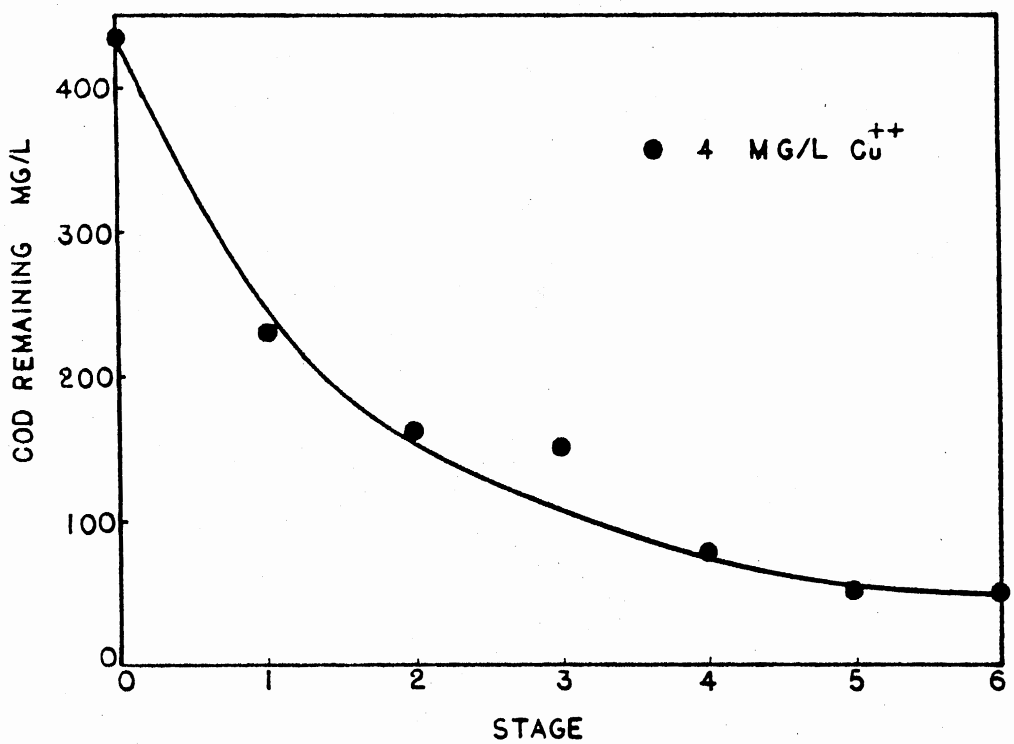

Figure 20. COD Remaining vs. Stage for Hydraulic Loading of 3 gpd/ft^2 When 4 mg/l Copper was Introduced

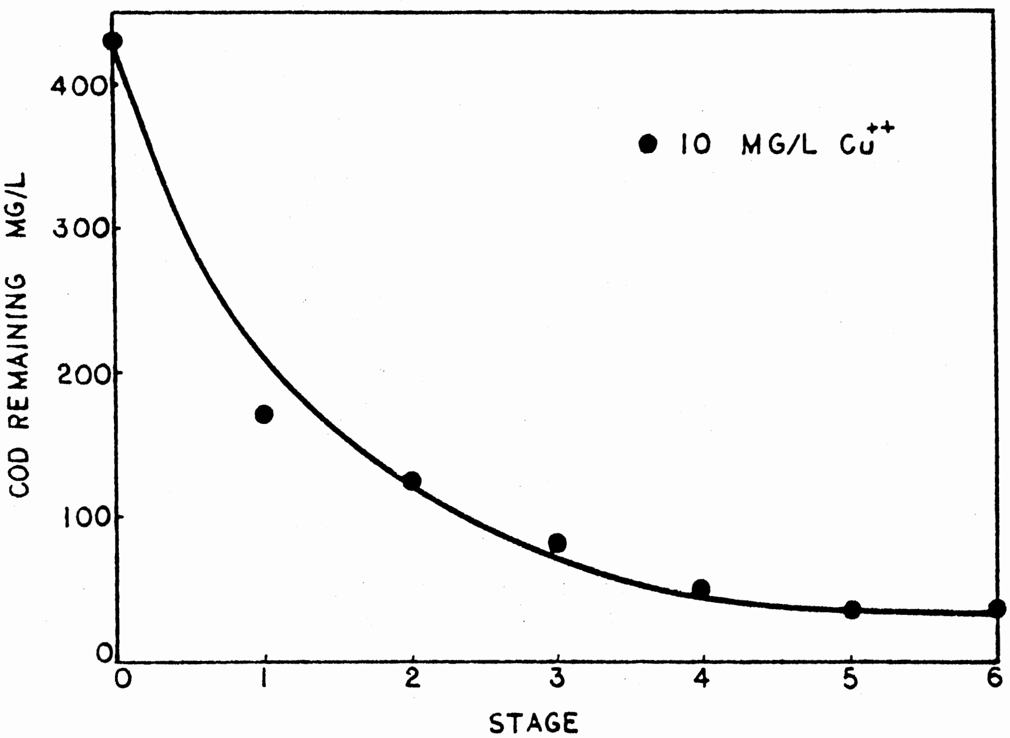

Figure 21. COD Remaining vs. Stage for Hydraulic Loading of 3 gpd/ft^2 When 10 mg/l Copper was fed

TABLE III

COD REMOVAL BY ROTATING BIOLOGICAL CONTACTOR (RBC) TREATMENT OF WASTEWATER CONTAINING $K_2Cr_2O_7$

Influent $K_2Cr_2O_7$ (mg/l)	COD Removal (%)
0	78
1	88
2	94
3	82
20	75

TABLE IV

REMOVAL EFFICIENCY OF HEXAVALENT CHROMIUM ($K_2Cr_2O_7$)

Influent $K_2Cr_2O_7$ (mg/l)	$K_2Cr_2O_7$ found in Effluent (mg/l)	$K_2Cr_2O_7$ Removal (%)
0	-	-
1	0.24	75
2	0.74	64
3	0.6	80
20	6.9	65.5

concentration, 6.9 mg/l $K_2Cr_2O_7$ remained in the effluent.

Table V shows the COD removal efficiency of the RBC. It is seen that the RBC produced a higher COD removal efficiency when the wastewater contained K_2CrO_4 relative to the control unit.

Table VI shows the K_2CrO_4 remaining in the effluent. It is seen that the RBC removed 1 and 2 mg/l K_2CrO_4 completely; however, at concentrations of 3 and 4 mg/l, the metal removal efficiency was 68 and 62 percent, respectively.

Microscopic examinations were made during the changing of chromium concentrations. They indicated that no change in the type of microorganisms was observed for any of the different concentrations of chromium (Cr^{+6}).

Visual observations showed that black and red worms were seen in the film growing on the discs, and the worms had the greatest population at 20 mg/l potassium dichromate ($K_2Cr_2O_7$).

Table VII shows that in general the RBC produced a better effluent when the wastewater contained copper as opposed to when the wastewater contained no copper. The only exception to this was when the RBC was operated at a hydraulic loading of 3 gpd/ft^2 and a Cu^{++} concentration of 1 mg/l. No explanation for this is available.

Table VIII shows the copper remaining in the effluent at a hydraulic loading of 0.7 gpd/ft^2. In general, very low removal efficiencies of copper were noted. However, fairly good removal efficiencies of copper were noted at a hydraulic loading of 3.0 gpd/ft^2. This is shown in Table IX. It is seen that 80 to 96 percent removal efficiencies were achieved by the RBC. No reason for this difference occurring at different hydraulic loadings is available.

TABLE V

COD REMOVAL BY ROTATING BIOLOGICAL CONTACTOR (RBC) TREATMENT OF WASTEWATER CONTAINING K_2CrO_4

Influent K_2CrO_4 (mg/l)	COD Removal (%)
0	78
1	93.5
2	93
3	92
4	95

TABLE VI

REMOVAL EFFICIENCY OF K_2CrO_4

Influent K_2CrO_4 (mg/l)	Effluent K_2CrO_4 (mg/l)	K_2 CrO_4 Removal (%)
0	-	-
1	0	100
2	0.08	96
3	0.96	68
4	1.51	62

TABLE VII

COD REMOVAL BY ROTATING BIOLOGICAL CONTACTOR (RBC) TREATMENT OF SEWAGE CONTAINING COPPER SULFATE

Influent Copper (mg/l)	COD Removal % at 0.7 gpd/ft^2	COD Removal % at 3 gpd/ft^2
0	87	78
0.5	94	90.6
1	92.6	70
4	92.4	88.5
10	93	91.4

TABLE VIII

REMOVAL EFFICIENCY OF COPPER SULFATE AT 0.7 gpd/ft^2

Influent Copper (mg/l)	Effluent Copper (mg/l)	Copper Removal (%)
0	0	0
0.5	0.5	0
1	0.64	36
4	2.73	31.7
10	8.5	15

TABLE IX

REMOVAL EFFICIENCY OF COPPER SULFATE AT $3.0\ gpd/ft^2$

Influent Copper (mg/l)	Effluent Copper (mg/l)	Copper Removal (%)
0	0	0
0.5	0.02	96
1	0.11	89
4	0.25	94
10	2.0	80

CHAPTER V

CONCLUSIONS

The following conclusions were drawn from this work:

1) Addition of hexavalent chromium in the form of K_2CrO_7 at concentrations of 1, 2, and 3 mg/l did not decrease COD removal efficiency of the RBC. However, chromium at 20 mg/l decreased COD removal efficiency.

2) The RBC receiving wastewater containing $K_2Cr_2O_7$ removed 65 to 80 percent metal at concentrations of 1, 2, 3, and 20 mg/l.

3) Hexavalent chromium (K_2CrO_4) at concentrations of 1, 2, 3, and 4 mg/l did not affect the COD removal efficiency of the RBC.

4) Removal efficiency of K_2CrO_4 by the RBC was nearly 100 percent at 1 and 2 mg/l concentrations, but only 68 percent and 62 percent of the metal was removed at 3 and 4 mg/l concentrations, respectively.

5) When hexavalent chromium in both forms ($K_2Cr_2O_7$ and K_2CrO_4) were fed to the RBC, the microbial growth was stimulated on the discs relative to control conditions.

6) The RBC receiving wastewaters containing copper were found to have higher COD removal efficiency at hydraulic loadings of 0.7 and 3 gpd/ft^2 relative to the control.

7) The results of the study showed that copper removal was considerably higher at a hydraulic loading of 3 gpd/ft^2 than at a hydraulic loading of 0.7 gpd/ft^2.

CHAPTER VI

SUGGESTIONS FOR FUTURE WORK

As a result of observations during the experimental work, the following suggestions are made for further study:

1) There is need to study the RBC operation at two or three additional hydraulic loadings with Cr^{+6}.

2) The RBC could be fed Cr^{+3} to compare its toxicity effect with Cr^{+6}.

3) There is need to study the effect of metals, viz., Cr^{+6} and Cu^{++} on nitrification on RBC.

4) Since temperature and pH may have an effect on metal toxicity, the unit can be operated at different degress of temperature and pH.

5) The effects of Cr^{+6} ($K_2Cr_2O_7$) upon RBC at concentrations between 3 mg/l and 20 mg/l should be investigated.

6) Oxygen uptake can be measured, and then the degree of metal toxicity determined.

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